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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Reissue Application of) Examiner: C. Verdier
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DAVID A. SPEAR ET AL.) Group Art Unit: 3745
:)
Appln. No.: 09/874,931)
:)
Filed: June 5, 2001)
:)
For: SWEPT TURBOMACHINERY BLADE) Application to reissue
U.S. Patent 5,642,985

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

DECLARATION OF FRANS A.E. BREUGELMANS

Sir:

I, Frans A.E. Breugelmans, do hereby declare as follows:

1. In 1962 I received from Leuven University in Belgium the degree of Master of Science in Mechanical Engineering (also known as a Civil Engineer degree). In 1963 I completed post-graduate studies at the Training Center for Experimental Aerodynamics, which in 1964 was renamed the Von Karman Institute ("VKI"). VKI is a non-profit educational and scientific organization with departments in aeronautics and aerospace, environmental and applied fluid mechanics, and turbomachinery and propulsion. See <http://www.vki.ac.be>. From 1963 to 1976, I lectured and performed research and development in the VKI turbomachinery and propulsion department. In 1976 and 1977 I was a visiting associate professor in the Mechanical Engineering Department of Iowa State University, Ames, Iowa, lecturing on the physics and aerodynamics of the flow in gas turbine engine compressors and fans. In 1977 I returned to VKI as a full professor in the turbomachinery and propulsion department. From 1977 to 1997 I was

the head of that department, and from 1991 to 2000 I was the assistant director of VKI. I retired from VKI in 2000, and I am currently an honorary professor in the VKI turbomachinery and propulsion department. During my professional career, up to and including the present, I have also been involved with numerous educational and professional organizations other than VKI, as a result of my recognized expertise in gas turbine engine compressors and fans. My *Curriculum Vitae*, attached hereto as Exhibit 1, lists the professional positions and memberships I hold or have held.

2. At VKI, I have designed numerous gas turbine engine components, including compressors and fans, for research and development projects sponsored by private industry and governmental organizations. These include the design, construction, and testing of supersonic compressors for the United States Air Force, developing blade sections for transonic and supersonic fans, and compressor stall studies, to name just a few. A more complete list is included in my *Curriculum Vitae*.

3. I am named as an author on numerous publications and project reports in the field of gas turbine engines, most of which publications and reports relate to the physics and aerodynamics of the flow in axial-flow compressors and fans of compressors. A list of my publications is included in my *Curriculum Vitae* (Exhibit 1). I am named as an inventor on U.S. Patent Appln. Pub. No. 2002/0066267 A1.

4. As a result of my education, training, and experience, I have expertise in the analysis of the flow through axial-flow turbomachinery, particularly compressors and fans, for gas turbine engines, and in the physics and aerodynamics of the interaction of gas turbine engine working medium gases with the blades and ducts of axial-flow fans for gas turbine engines.

5. The subject matter discussed in this declaration involves complex, supersonic fluid flow through the fan of a gas turbine turbofan engine. Knowledge of some basic principles of jet

propulsion and fluid mechanics is required to understand the topics discussed herein. To that end, attached Exhibit 2 explains some of the fundamentals of those subjects.

6. In connection with this declaration I have studied U.S. Patent No. 5,642,985 to David A. Spear et al. ("the UTC '985 Patent") (attached as Exhibit 3), reissue of which I am informed is sought by the above-identified present application ("the UTC Reissue Application"). On information and belief, claims 18, 19, 22, and 23 set forth elsewhere herein are to be presented in the UTC Reissue Application. I have also studied the patent and literature references listed on the Information Disclosure Citation forms attached hereto as Exhibit 4.

7. It is my understanding that the UTC Reissue Application was filed to initiate an interference in the U.S. Patent and Trademark Office with U.S. Patent No. 6,071,077 to Paul A. Rowlands, which names as its assignee Rolls-Royce PLC ("the Rolls '077 Patent") (attached as Exhibit 5). It is also my understanding that the UTC Reissue Application has the same disclosure as the UTC '985 Patent. I have studied the Rolls '077 Patent in connection with this declaration.

The Common Invention Of The UTC '985 Patent And The Rolls '077 Patent

8. The claims in the present application and their relation to the claims in the Rolls '077 Patent are discussed in detail below. However, I believe the discussion in that regard will be better understood by first considering in general the subject matter of the UTC '985 Patent, which is the precursor to the present application, and the Rolls '077 Patent. (Technical terms and concepts in the following discussion are explained more fully in Exhibit 2.)

9. The Rolls '077 Patent and the UTC '985 Patent both relate to a fan stage of a ducted fan gas turbine engine, and more particularly to an advantageous blade configuration for such a fan. The fan shown in Figures 1 and 2 of the UTC '985 Patent has multiple blades disposed in a duct. UTC '985 Patent, col. 2, lines 42-44 and 56-58. The blades are swept to minimize the

adverse effects of supersonic flow of the working medium over the blades. UTC '985 Patent, col. 1, lines 4-7. The Rolls '077 Patent also relates to a ducted fan gas turbine engine having swept fan blades. Rolls '077 Patent, col. 1, lines 7-10.

10. The fans in both patents rotate at speeds that produce supersonic flow over the fan blades at some point along the blade span. UTC '985 Patent, col. 3, lines 6-10; Rolls '077 Patent, col. 1, lines 31-33. This supersonic flow causes the formation of shock waves and reduces the efficiency of the fan. UTC '985 Patent, col. 3, lines 10-14; Rolls '077 Patent, col. 1, lines 38-45. It was well known prior to 1995 that sweeping the leading edge of a supersonic fan blade will mitigate these losses. UTC '985 Patent, col. 1, lines 27-31; Rolls '077 Patent, col. 3, lines 11-20 and 41-45. (The terms "sweep" and "sweep angle" have accepted definitions, used in both the UTC '985 Patent, col. 3, lines 20-29, and the Rolls '077 Patent, col. 2, lines 5-10).

11. To that end, each of the UTC and Rolls fan blades has a leading edge with forward sweep in an inner region followed by a rearward swept intermediate region, as seen in Figure 2 of the UTC '985 Patent and Figure 5a of the Rolls '077 Patent. As noted in paragraph 10, the rearward sweep in the intermediate region is important because it mitigates shock losses and thus increases the fan's efficiency, by reducing the Mach number of the supersonic airflow in a direction perpendicular to the blades' leading edges. UTC '985 Patent, col. 3, lines 14-18; Rolls '077 Patent, col. 3, lines 14-17. Forward sweep in the inner region of a blade had been used previously to make a blade with rearward sweep further out along the blade (that is, in the intermediate region) practicable from the standpoint of the mechanical stresses on the blade. Exhibit 2, paras. 23-26; see also U.S. Patent 4,012,172 to Schwaar et al. ("Schwaar") (attached as Exhibit 6) and U.S. Patent 4,726,737 to Weingold et al. ("Weingold") (attached as Exhibit 7). The Rolls '077 Patent at column 3, lines 30-33, alludes to the mechanical reasons for using forward sweep in the inner region.

12. Accordingly, the forward-rearward swept blade geometry described thus far (a leading edge swept forward in an inner region and swept rearward outwardly therefrom) was known before the filing dates of the applications that became the UTC '985 and Rolls '077 Patents. In addition, the prior art recognized the difficulties in using a blade with a rearward swept leading edge, and proposed numerous approaches for overcoming those difficulties and maximizing the advantages of operating gas turbine engine fan blades in a supersonic flow regime. Those working in the art were aware that supersonic fan blades should have performed better with a rearward swept region radially outward of a forward swept inner region, but no such blade ever gained wide acceptance. Schwaar, Weingold, and U.S. Patent 3,989,406 to Bliss ("Bliss") (attached as Exhibit 8) proposed improving the aerodynamic performance of such a blade by providing a high degree of rearward sweep to render subsonic the flow perpendicular to the leading edge, thereby eliminating shocks altogether. Those solutions were impracticable. Exhibit 2, paras. 23-26.

13. A principal problem with prior forward-rearward swept blades is that a shock can form in front (that is, upstream) of the blade in an outer tip region near the duct wall. UTC '985 Patent, Figs. 2 and 3 (endwall shock 64, see also col. 3, lines 30-40); Rolls '077 Patent, Fig. 3a (showing the shock wave 36 in front of the blade in the tip region). The UTC '985 Patent and the Rolls '077 Patent provide slightly different depictions of the shock system created by such a blade, but both point out that it can include a shock upstream of the blade in the tip region. Such a shock results in a decrease in operational efficiency, and can cause heavy vibration and fan stalling and surge, which requires corrective action to overcome in cases where the stalled fan fails to provide sufficient airflow for engine operation. UTC '985 Patent, col. 3, lines 55-57; Rolls '077 Patent, col. 3, lines 41-45, col. 4, lines 11-17.

14. The same feature of the blade in the UTC '985 Patent and the Rolls '077 Patent solves that problem: a blade leading edge outer region is translated forward relative to the more highly swept leading edge at the end of the intermediate region, thereby preventing the shock from forming ahead of the leading edge. UTC '985 Patent, col. 4, line 63, to col. 5, line 4; Rolls '077 Patent, col. 4, lines 18-21, and col. 7, lines 28-30.

15. The UTC '985 Patent explains that the shock system includes an endwall shock portion adjacent the duct wall and a passage shock portion across the passages between the fan blades. See col. 3, lines 30-57, and col. 4, lines 37-44. The passage shock portion extends across each interblade flow passage, col. 3, lines 50-52, col. 4, lines 42-44, and Fig. 3, because the blade leading edge's intermediate region travels faster than the speed of sound ($M > 1$) relative to the incoming flow and creates a shock wave, as would be expected.

16. The UTC '985 Patent says that the shape of the blade influences the shock in the endwall region, adjacent the duct wall, because pressure waves generated by the blades are reflected by the wall. Under certain conditions, a shock wave forms ahead of each blade's leading edge. UTC '985 Patent, col. 3, lines 36-40, and Fig. 2 (endwall shock 64).

17. The Rolls '077 Patent likewise points to a shock 36 with a portion in each interblade passage, and also shows that the rearward swept leading edge at the blade outer region can cause another shock portion to form ahead of each blade's leading edge. The Rolls '077 Patent explains the origins of the shock slightly differently, col. 3, line 60, to col. 4, line 6 (which I believe was intended to refer to the depiction in Figs. 3a and 3b, rather than Figs. 4a and 4b), but both patents nonetheless describe virtually identical shock systems.

18. From the teachings in the Rolls '077 Patent and the UTC '985 Patent, one skilled in this art would have understood at the time the UTC and Rolls patent applications were filed, and would understand now, that both patents teach that the blade leading edge in the tip region must

be translated forward a sufficient distance to cause the blade to intercept the shock near the duct wall. UTC '985 Patent, col. 4, line 33, to col. 5, line 4; Rolls '077 Patent, col. 4, lines 18-21, and col. 7, lines 28-30. He or she would also have appreciated that those patents correctly teach that translating the tip region forward to reduce rearward sweep solved the problem of providing a practicable swept fan blade. See Exhibit 2, paras. 25-26.

19. That the Rolls '077 Patent explicitly calls for a forward swept leading edge in the blade outer region adds nothing to the teaching of the UTC '985 Patent. A fan engineer working at the time of the UTC '985 Patent's filing date obviously would have read it to teach the necessity of using a fan blade configuration that achieves endwall shock interception at all engine operating conditions. In my opinion the same fan engineer would have found that the prescription of the UTC '985 Patent, namely translating forward the leading edge of a forward-rearward swept blade in the outer region, inevitably leads to the use of the forward sweep called for by the Rolls '077 Patent. I believe that to be the case even under normal engine operating conditions. But it is especially true considering that at the time (as well as now) standard practice required fan operability not only under normal conditions, but also at the most severe operating conditions the engine would encounter. See Rolls '077 Patent, col. 1, lines 17-23. My expert opinion is that a fan engineer following the UTC '985 Patent's command to intercept the endwall shock under all engine operating conditions would have had to translate the leading edge of the blade's outer region sufficiently far forward to impart forward sweep as in the Rolls '077 Patent.

UTC Claims 18 And 23 And Rolls Claims 1 And 8 Define The Same Invention

20. UTC independent claim 18 and Rolls independent claim 8 are essentially broader in all respects relevant to this discussion than any other claim in the Rolls '077 Patent or the present

UTC Reissue Application. That is, all of the other claims in the Rolls '077 Patent and the present application contain additional features not found in these claims.

21. The following chart highlights the precise differences between UTC claim 18 and Rolls claim 8:

Present Application Claim 18

A fan stage of a ducted fan gas turbine engine that is rotatable about an axis of rotation and defines a downstream direction along the axis of rotation, comprising:

a fan casing that defines an inner duct wall having a fan rotor region;

a hub disposed concentrically relative to the fan casing;

a fan rotor that includes multiple swept fan blades, the swept fan blades being spaced apart around the hub, each of the multiple swept fan blades having:

a tip profile that corresponds to the inner duct wall of the fan casing;

a leading edge that defines a variable sweep angle in a direction perpendicular to the axis of rotation, the leading edge including:

an inner region adjacent the hub, the inner region defining a forward sweep angle;

an intermediate region between the inner region and the fan casing, the intermediate region defining a rearward sweep angle; and

an outer region between the intermediate region and the fan casing, the outer region being translated forward relative to a leading edge with the same sweep angle as an outward boundary of the intermediate region.

Rolls '077 Patent Claim 8

A fan stage of a ducted fan gas turbine engine that is at least in part rotatable about an axis of rotation and defines a downstream direction along the axis of rotation, comprising:

a fan casing that defines an inner duct wall having a fan rotor region, the inner duct wall of the fan casing at the fan rotor region being convergent;

a hub disposed concentrically relative to the fan casing;

a fan rotor that includes multiple swept fan blades, the swept fan blades being spaced apart around the hub, each of the multiple swept fan blades having:

a tip profile that is convergent so as to substantially correspond to the convergent inner duct wall of the fan casing;

a leading edge that defines a variable sweep angle in a direction perpendicular to the axis of rotation, the leading edge including:

an inner region adjacent the hub, the inner region defining a forward sweep angle;

an intermediate region between the inner region and the fan casing, the intermediate region defining a rearward sweep angle; and

an outer region between the intermediate region and the fan casing, the outer region defining a forward sweep angle.

22. The first feature in Rolls's claim missing from UTC's claim is that the fan stage is "at least in part" rotatable. This recitation adds nothing of substance to the Rolls claim. First of all, the recitation appears in a portion of the claim that simply introduces the structural features of the fan stage recited in the rest of the claim; that is, it does not actually recite any structural feature of the fan stage itself. In addition, the rotatable parts of the fan stage recited in UTC claim 18 (the hub and the rotor) are rotatable in the same fashion as the corresponding parts in Rolls claim 8.

23. The first feature with any substance in a technical sense that is included in Rolls's claim but is not found in UTC's claim is a duct wall that is convergent at the fan rotor region and a blade tip profile that is convergent so as to substantially correspond to the convergent inner duct wall of the fan casing.

24. One of ordinary skill in the art of designing fan stages for ducted fan gas turbine engines would have used a convergent duct wall and matching convergent blade tips for a number of reasons. First, fans with convergent casings and matching blade tip profiles had been conventional for decades by the time of the filing dates of the UTC '985 Patent and the Rolls '077 Patent, as shown in Fig. 1 of U.S. Patent 4,408,957 to Kurzrock et al. (attached as Exhibit 9), Fig. 2 of U.S. Patent 5,408,826 to Stewart et al. ("Stewart") (attached as Exhibit 10), Fig. 1 of Schwaar, and Fig. 1-14 of The Aircraft Gas Turbine Engine and Its Operation, Section 1, United Technologies Corporation, Part No. P&W 182408 (1988), page 1-17 (attached as Exhibit 12).

25. I note also that the Rolls '077 Patent does not assert that a convergent duct wall and matching blade tip profile in combination with the disclosed blade leading edge geometry provides any advantage that would not have been known to those skilled in the art. The Rolls '077 Patent, at column 6, lines 21-26, points to the discussion in the UTC '985 Patent of a convergent casing. However, in my opinion the Rolls '077 Patent misconstrues what the UTC

'985 Patent says in that regard. The discussion in question in the UTC '985 Patent actually says that the casing wall can be made convergent to ameliorate the problem of pressure wave reflection. At the same time, the '985 Patent teaches that mechanical and aerodynamic constraints may not permit convergence in a manner that eliminates the problems caused by shock waves discussed above in paragraphs 13-19. UTC '985 Patent, col. 3, lines 58-63. Then, just like the Rolls '077 Patent, the UTC '985 Patent says that the blade configuration provides the solution. UTC '985 Patent, col. 3, lines 64-67.

26. Furthermore, the prior art teaches the conventionality of providing UTC claim 18's fan with a convergent blade tip profile that substantially corresponds to a convergent fan casing. For example, Stewart, which discloses such structure, explains that it is important to make the radial clearance between the blade tip and the casing as small as possible. Stewart does this by providing an abradable coating 25 on the convergent casing and cutting a convergent path through the coating with the converging blade tips to ensure that the convergent casing and blade tips conform exactly. Stewart, col. 3, lines 45-50.

27. The only other difference between UTC claim 18 and Rolls claim 8 is that UTC claim 18 recites a blade leading edge outer region that is "translated forward relative to a leading edge with the same sweep angle as an outward boundary of the intermediate region." Rolls claim 8 recites this feature differently, calling for an outer region "defining a forward sweep angle."

28. As discussed in paragraph 19, the UTC '985 Patent teaches that the blade tip leading edge must be moved forward to intercept the shock wave adjacent the duct wall. Once one skilled in the art had been taught by UTC claim 18 to translate the outer region forward, that person would have inevitably provided a forward sweep angle for the reasons discussed above in paragraph 19. Stated another way, UTC claim 18 recites a blade that reduces leading edge sweep

in an outer or tip region for the same reason as the blade recited in Rolls claim 8: to move the shock behind the blade leading edge so the blade intercepts the shock near the fan casing. See Rolls '077 Patent, col. 4, lines 18-21. A fan engineer following that teaching would have been compelled to introduce the forward sweep recited in Rolls claim 8.

29. Therefore, it is my opinion that the subject matter of UTC claim 18 would have taught a fan engineer of ordinary skill the subject matter of Rolls claim 8.

30. UTC claim 18 does not explicitly call for intercepting the shock wave at the duct wall. However, UTC claim 23, which is otherwise identical to claim 18, recites that the blade tip leading edge sweep angle causes interception of that shock. Accordingly, UTC claim 23 merely explicitly recites a feature of Rolls claim 8's blade and of UTC claim 18's blade as taught by both the Rolls '077 Patent and the UTC '985 Patent. Thus, it is my opinion that the subject matter of each of UTC claim 18 and Rolls claim 8 would have taught a fan engineer of ordinary skill the subject matter of UTC claim 23.

31. UTC claim 23 does not include the limitations in Rolls claim 8 discussed in paragraphs 21-28. However, UTC claim 23 is identical to UTC claim 18, except that claim 23 explicitly recites the shock-intercepting feature of the blade of both UTC claim 18 and Rolls claim 8. Accordingly, the subject matter of UTC claim 23 would have taught a fan engineer of ordinary skill the subject matter of Rolls claim 8, for the reasons discussed in paragraphs 21-28.

32. The difference between Rolls '077 Patent claims 1 and 8 (other than differences in terminology that do not affect this analysis) is that claim 1's blade has a "stagger angle which increases progressively with blade height." However, fan engineers working at the time of the UTC and Rolls filing dates knew that to be a necessary feature of all fan blades.

33. Schwaar explains that a blade's stagger angle (or the "blade twist") must increase progressively with blade height because the blade's circumferential velocity (" V_x " in Fig. 2 of

Schwaar) progressively increases with blade height, while the axial airflow velocity (" V_y " in Fig. 2 of Schwaar) remains essentially constant. As Schwaar points out, it is a "basic consideration of blade design" that the twist angle " t " shown in Fig. 2 increases with blade height. Schwaar, col. 3, line 66, to col. 4, line 21. Accordingly, this limitation is not just obvious in view of the subject matter of Rolls claim 8; it is a necessary and inherent feature of any fan blade as explained in more detail in Exhibit 2, at paragraphs 20-21. Nor does providing a progressively increasing stagger angle perform any new function or achieve a different result when used in a blade that has a converging tip matching a converging duct wall and explicitly recited forward sweep in the tip region. That is, such a blade is subject to the same increasing velocity along the blade span as conventional blades, and must also have the increasing stagger angle feature in Rolls claim 1. Another way of saying the same thing is that by calling them "fan blades," Rolls claim 1 requires that they have a progressively increasing stagger angle. Otherwise, the blades could not perform the function required of them as part of a "fan stage for a ducted fan gas turbine engine."

Rolls Claims 2-7 And 9-13 Define The
Same Invention As UTC Claims 18 And 23

34. Rolls '077 Patent claim 2 depends from claim 1 and reads as follows:

A fan stage of a ducted fan gas turbine engine as claimed in claim 1 wherein the blade has a tip region of about 20% of blade height characterised in that the stagger angle increases to approximately 70° at the tip relative to the airflow direction.

35. This claim recites a "tip region," but that term is entirely self-referential within claim 2 and has no other definition except that it constitutes an arbitrary amount (20%) of the blade's span. As a result, this limitation does not relate to any actual blade structure.

36. However, if this "tip region" is taken as being the portion of the blade in which the leading edge transitions from rearward sweep to claim 1's forward swept third height region, then one of ordinary skill in the art would have known to chose any suitable place on the leading

edge, such as 20% of the blade height for a particular ducted fan gas turbine engine, at which to begin the transition to forward sweep. Put another way, UTC claims 18 and 23, and Rolls claims 1 and 8, "teach" a blade with a leading edge profile with an outer region that is moved forward to provide certain aerodynamic advantages. A fan engineer designing for a particular engine, knowing the purpose of translating the blade outer region forward, would have found the proper place, such as the last 20% of the blade height, at which to begin the forward translation.

37. As for the recitation of a stagger angle at the blade tip of approximately 70° relative to the airflow direction, a fan engineer would have found this to be a routine matter of blade design for the same reasons that the recited extent of the forward swept tip region would have been obvious. That is, an ordinarily skilled fan engineer, faced with a set of engine operating conditions, would have simply made a blade with a stagger angle at the tip that would satisfy the requirement that the flow approach the blade at the proper angle. See Exhibit 2, paras. 20-21. That the angle might be 70° relative to the airflow direction for a given fan stage would simply be a matter of proper engineering. I note also that the stagger angle "t" at the blade tip as measured in Fig. 2 of Schwaar is about 70°, although I cannot be certain that drawing is to scale.

38. Dependent claim 3 of the Rolls '077 Patent reads as follows:

A fan stage of a ducted fan gas turbine engine as claimed in claim 2 wherein [sic - in?] a blade tip region of about 20% of blade height the sweep of the leading edge changes from rearward sweep to forward sweep.

39. The subject matter of this claim would have been suggested to a fan engineer by UTC claims 18 and 23, and Rolls claims 1 and 8, for the same reasons discussed in paragraph 36 relating to claim 2.

40. Dependent claim 4 of the Rolls '077 Patent reads as follows:

A fan stage of a ducted fan gas turbine engine as claimed in claim 3 wherein the blade is further characterised in that the stagger angle of the mid-height region of

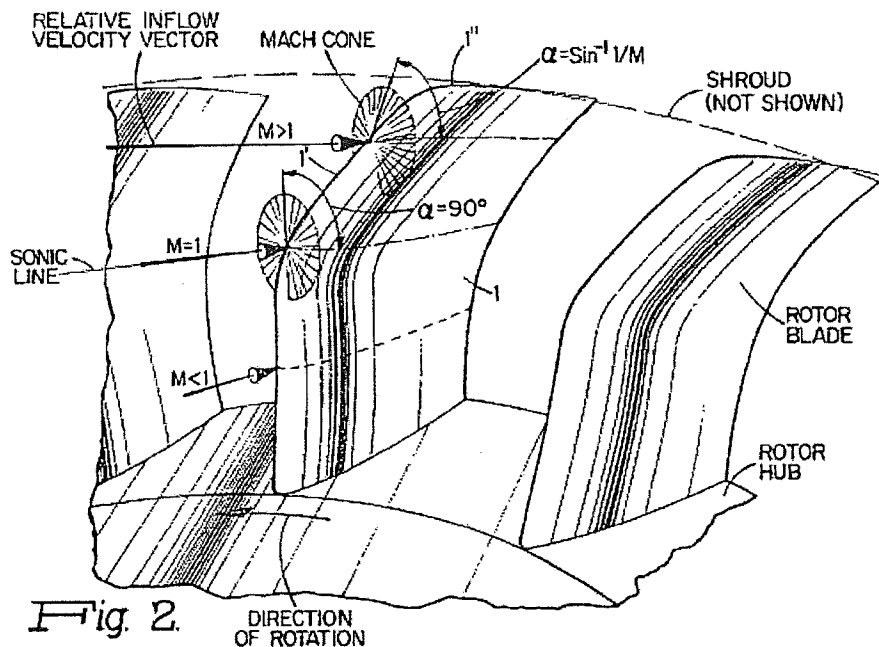
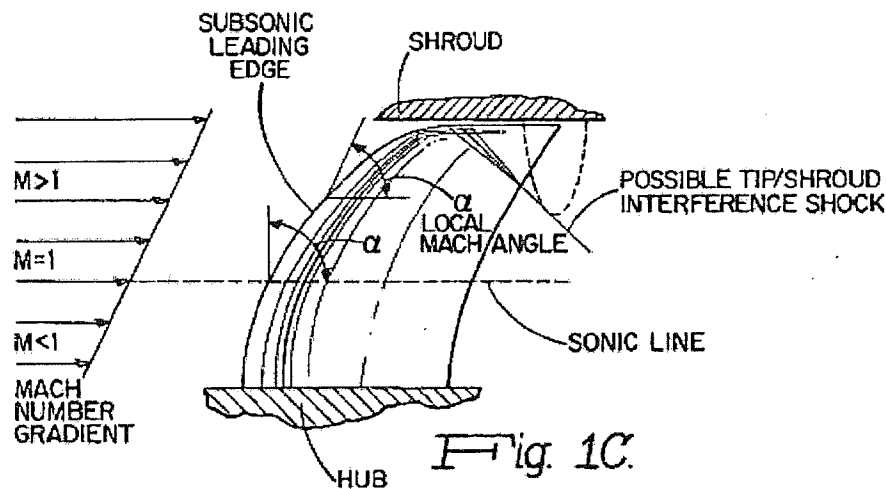
the blade is in the range from approximately 30° to approximately 55° relative to the airflow direction.

41. The subject matter of this claim would have been suggested to a fan engineer by the subject matter of UTC claims 18 and 23, and Rolls claims 1 and 8, for the same reasons discussed in paragraph 37 relating to claim 2. That is, the stagger angle of a fan blade at any particular point on the blade is simply a function of the engine operating conditions and the requirement that the flow approach the blade at the proper angle along the entire blade span. A fan engineer would have routinely designed a fan blade with the stagger angle characteristics in claim 4 if that is what the engine operating conditions dictated. I note also that Fig. 6 of Schwaar shows a swept fan blade with a stagger angle that measures between 30° and 55° in the blade mid-height region, although I cannot be certain that drawing is to scale.

42. Dependent claim 5 of the Rolls '077 Patent reads as follows:

A fan stage of a ducted fan gas turbine engine as claimed in claim 1 wherein the sweep angle of the leading edge of a swept fan blade at a point on the leading edge is less than the complement of the angle of a Mach cone at any other point on the leading edge of the blade at greater radius from the root.

43. To understand why the feature in this claim is anticipated by UTC claims 18 and 23, and Rolls claims 1 and 8, it is first necessary to understand the concept of a "Mach cone." As explained in Exhibit 2, paragraph 13, describing aspects of supersonic flow using Mach cones and Mach angles is not new with the Rolls '077 Patent. Bliss is an example of an earlier reference that discusses Mach cone angles. Figs. 1C and 2 from Bliss, reproduced below, illustrate Mach angles and Mach cones associated with a blade leading edge:



44. Bliss's Figure 1C shows the radial gradient associated with the velocity of the air approaching the blade, while Figure 2 is a three-dimensional depiction of theoretical Mach cones associated with points on a fan blade leading edge. (See Exhibit 2, Fig. 5 and para. 13.) Bliss shows a blade with a leading edge swept to a degree that it is always subject to subsonic velocities, thus theoretically eliminating the difficulties associated with shock waves. This is the opposite of Rolls claim 5, in that Bliss's sweep angle (call it " σ ") is greater than the complement of the Mach cone angle α (that is, $\sigma > 90^\circ - \alpha$).

45. In light of those known principles, Rolls claim 5 does no more than use different words to say the same thing as UTC claims 18 and 23 and Rolls claims 1 and 8. Put another way, consider what would happen if those UTC and Rolls claims did not meet claim 5: there would be no shock system to account for by using the leading edge configuration in those claims. Furthermore, UTC claim 23 explicitly recites the presence of a shock wave in the flow, meaning that its leading edge must have the Mach cone relationship recited in Rolls claim 5. Accordingly, the leading edge orientation in Rolls claim 5 is anticipated by UTC claims 18 and 23 and Rolls claims 1 and 8.

46. Dependent claim 6 of the Rolls '077 Patent reads as follows:

A fan stage of a ducted fan gas turbine engine as claimed in claim 1 wherein the shape of the pressure surface of a swept fan blade and the suction surface thereof creates, in use, a line of minimum static pressure points on the suction surface of the blade, said line of minimum static pressure points is inclined with respect to the axial direction at a sweep angle which varies with span height of the blade, and has a negative value in a region of subsonic flow over the leading edge.

47. It will be appreciated immediately that, by definition, a gas turbine engine fan blade is an airfoil with a suction surface and a pressure surface (see Exhibit 2, Figure 6 and paras. 20-21; see also Fig. 3 of Weingold). Accordingly, at each location along the blade height, the suction surface will inherently have a minimum static pressure point. The locus of those points will, again by definition, be a line of minimum static pressure points.

48. As a practical matter, good fan blade design has always required that the line of minimum static pressure points for a swept fan blade essentially follow the leading edge profile, as shown in Weingold. In other words, given the leading edge geometry of the blades in UTC claims 18 and 23, and Rolls claims 1 and 8, and conventional fan design practice as exemplified by Weingold, an ordinarily skilled fan engineer would have inclined the lines of minimum static pressure points in those claims at a sweep angle that varied with blade height, and that sweep

angle would have been negative in the inner, subsonic-flow region of the blade, just as in Rolls claim 6.

49. Dependent claim 7 of the Rolls '077 Patent reads as follows:

A fan stage of a ducted fan gas turbine engine as claimed in claim 6 wherein the sweep angle of the line of minimum static pressure points at a point on the line is less than the complement of a Mach cone angle at any other point on the line.

50. This claim relates to the same concept as claim 5. Mach cones associated with a blade's line of minimum static pressure points were known from Weingold, which is referred to in the Rolls '077 Patent at column 7, lines 25-27. Fig. 2a of Weingold illustrates Mach cones 38,44 associated with a line of minimum static pressure points:

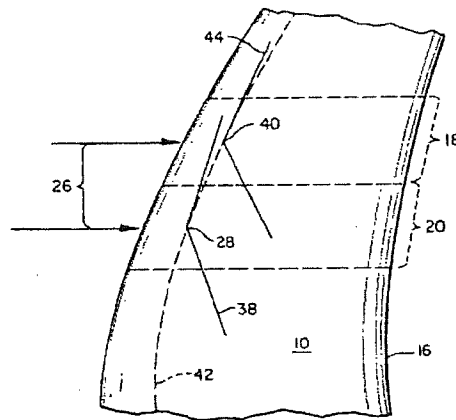


FIG. 2a

51. Weingold put the blade's maximum camber line 42 (associated with the line of minimum pressure points) behind the Mach cone associated with any inboard point of maximum camber. As in Bliss, the purpose of Weingold's geometry was to eliminate shock waves. Like Rolls claim 5, claim 7 puts the line of minimum static pressure points ahead of the Mach cone, the opposite of Weingold's geometry.

52. Accordingly, Rolls claim 7 does no more than recite a blade that creates shock waves, as discussed in paragraphs 44 and 45. But unless the blades in UTC claims 18 and 23, and Rolls claims 1 and 8, also create shock waves, there is no reason for them to have the

geometry that represents the invention embodied in those claims. And UTC claim 23 explicitly recites the presence of a shock system, which means it even more clearly anticipates claim 7's recitation of a particular orientation of the blade's line of minimum static pressure points.

53. Dependent claim 9 of the Rolls '077 Patent reads as follows:

The fan stage according to claim 8, wherein the intermediate region extends further than the inner region along the axis of rotation.

54. This claim is ambiguous, since it is not clear what part of the blade's intermediate region is meant to "extend" further than the inner region along the rotational axis. Based on the disclosure of the Rolls '077 Patent at column 5, lines 23-51, and especially lines 26-28, I believe this claim means to say that the blade leading edge at the boundary between the inner and intermediate regions (segment S₅ in Figure 7a), is further upstream along the axis than the inner region leading edge (from the hub to segment S₅). As is the case with claims 5 and 7 (see paragraphs 42-52), this claim does no more than recite a feature of the blades in UTC claims 18 and 23, and Rolls claims 1 and 8. That is, a blade with forward sweep in the inner region and a rearward swept intermediate region must have claim 9's configuration. See Figures 1 and 2 of the UTC '985 Patent, Figures 3a, 5a, and 7a of the Rolls '077 Patent, and Figures 4 and 6 of Schwaar.

55. Dependent claim 10 of the Rolls '077 Patent reads as follows:

The fan stage according to claim 8, wherein the inner duct wall of the fan casing at the fan rotor region is substantially convergent in the downstream direction.

56. This is already a feature of claim 8, so it adds nothing to distinguish it from claim 8's subject matter. It also recites a conventional feature of a ducted fan gas turbine engine, as discussed in paragraphs 23-26.

57. Dependent claim 11 of the Rolls '077 Patent reads as follows:

The fan stage according to claim 8, wherein the tip profile of the swept fan blades are substantially convergent in the downstream direction.

58. As with claim 10, this is already a feature of claim 8, which means that it adds nothing to distinguish it from that claim. It also recites a conventional feature of a ducted fan gas turbine engine, as discussed above in paragraphs 23-26.

59. Dependent claim 12 of the Rolls '077 Patent reads as follows:

The fan stage according to claim 8, wherein inner duct wall of the fan casing is not parallel to the tip profile of each of the multiple swept fan blades.

60. This claim actually contradicts claim 8, which recites that the blade tip profile is configured to "substantially correspond to the convergent inner duct wall." Nonetheless, it would have been well within the skill of a fan engineer also to provide a fan casing with an inner wall that is not parallel to the blade tip profile, as shown in U.S. Patent 4,012,165 to Kraig ("Kraig") (Fig. 1; movable door 32) (attached as Exhibit 11). That is, a fan engineer would have recognized that Kraig's door 32 would perform the same function in the fan stages recited in UTC claims 18 and 23, and Rolls claims 1 and 8, as it does in Kraig's fan.

61. Dependent claim 13 of the Rolls '077 Patent reads as follows:

The fan stage according to claim 8, wherein each of the multiple swept fan blades includes a hub contacting surface that extends further than the tip profile along the axis of rotation.

62. This claim relates to physical properties of the blade rather than its aerodynamic performance. In my opinion the features recited in this claim are no more than the result of an ordinarily skilled fan engineer applying routine design techniques to determine optimum blade geometry within the performance and mechanical design parameters for the engine under consideration, and the Rolls '077 Patent does not say otherwise. That is, as discussed above with regard to other claims (see paragraphs 36, 37, and 41), a fan engineer would have provided a fan

blade with the geometry in claim 13 if performance and mechanical design criteria so dictated in making a blade in accordance with UTC claims 18 and 23 and Rolls claims 1 and 8.

UTC Claims 19 And 22 Define The Same Invention
As UTC Claims 18 And 23 And Rolls Claims 1 And 8

63. Dependent UTC claim 19, set forth in paragraph 67, is based closely on dependent claim 9 of the Rolls '077 Patent. Its subject matter is in accord with my understanding of the subject matter intended to be covered by Rolls claim 9, as discussed in paragraph 54. UTC dependent claim 22 is identical to Rolls claim 13.

64. Accordingly, I believe that a fan engineer would have concluded that the subject matter of each of UTC claims 19 and 22 have the same relation as each of Rolls claims 9 and 13 to the subject matter of UTC claims 18 and 23, and Rolls claims 1 and 8, for the reasons discussed above in paragraphs 54 and 62.

The '985 Patent Specification Discloses The
Subject Matter Of UTC Claims 18, 19, 22, And 23

65. The following discussion applies the terms of these UTC claims to the disclosure in the UTC '985 Patent.

Independent Claim 18

66. The following chart applies the terms of claim 18 to the disclosure in the UTC '985 Patent.

Present Application Claim 18

A fan stage of a ducted fan gas turbine engine that is rotatable about an axis of rotation and defines a downstream direction along the axis of rotation, comprising:

a fan casing that defines an inner duct wall having a fan rotor region;

UTC '985 Patent Disclosure

A gas turbine engine fan stage 10 has blades 12 circumscribed by a case 42 that forms a fan duct (Figs. 1 and 2; col. 2, lines 42-44 and 56-58). The fan is rotatable about an axis 18 (Fig. 2, col. 2, lines 44-46).

The case 42 defines an inner wall in a region that is axially coextensive with the blade 12 (Figs. 1 and 2; col. 3, lines 58-67).

a hub disposed concentrically relative to the fan casing;

a fan rotor that includes multiple swept fan blades, the swept fan blades being spaced apart around the hub, each of the multiple swept fan blades having:

a tip profile that corresponds to the inner duct wall of the fan casing;

a leading edge that defines a variable sweep angle in a direction perpendicular to the axis of rotation, the leading edge including:

an inner region adjacent the hub, the inner region defining a forward sweep angle;

an intermediate region between the inner region and the fan casing, the intermediate region defining a rearward sweep angle; and

an outer region between the intermediate region and the fan casing, the outer region being translated forward relative to a leading edge with the same sweep angle as an outward boundary of the intermediate region.

The hub 16, 20 and case 42 have the same centerline 18 and thus are concentric (Figs. 1 and 2; col. 2, lines 42-63).

The fan blades 12 are spaced apart around the hub. The blades are swept (col. 4, lines 11-17 and 24-29).

The blade 12, seen in Fig. 2 projected into the radial plane of the drawing, has a tip profile that corresponds to the inner wall of the case 42 (Figs. 1 and 2; col. 3, lines 26-29).

The blade leading edge 28 has an intermediate region 70 with a sweep angle σ_1 and a tip region 74 with a sweep angle σ_2 , both of which vary with increasing blade height (Fig. 2; col. 4, lines 11-17 and lines 24-29).

A first height region between the blade root 24 (that is, adjacent the hub 16,20) and $r_{t\text{-inner}}$ is swept forward (Fig. 2; col. 5, lines 55-58).

The intermediate region 70 between $r_{t\text{-inner}}$ and $r_{t\text{-outer}}$ is swept rearward (Figs. 1 and 2; col. 4, lines 11-13).

The tip region 74 between $r_{t\text{-outer}}$ and the blade tip 26 is translated axially forward relative to a conventional blade (col. 4, line 62, to col. 5, line 5).

Dependent Claims 19 And 22

67. Dependent claim 19 conforms to my understanding of the intended meaning of

Rolls claim 9, discussed in paragraph 54. Claim 19 reads as follows:

The fan stage according to claim 18, wherein the leading edge at a boundary between the intermediate region and the inner region extends further upstream along the axis of rotation than the inner region.

68. Fig. 2 of the UTC '985 Patent shows the subject matter of this claim. That is, Fig. 2, being a projection of the blade onto the plane of the figure (see col. 3, lines 26-29), shows the blade at $r_{t\text{-inner}}$ extending further upstream along the axis 18 than the region inward thereof.

69. Dependent claim 22 is identical to dependent claim 13 of the Rolls '077 Patent. It reads as follows:

The fan stage according to claim 18, wherein each of the multiple swept fan blades includes a hub contacting surface that extends further than the tip profile along the axis of rotation.

70. Fig. 2 of the UTC '985 Patent shows that the blade's hub contacting surface at the root 24 extends further along the axis 18 than at the blade tip 26.

Independent Claim 23

71. The following chart applies the terms of claim 23 to the disclosure in the UTC '985 Patent.

Present Application Claim 23

A fan stage of a ducted fan gas turbine engine that is rotatable about an axis of rotation and defines a downstream direction along the axis of rotation, comprising:

a fan casing that defines an inner duct wall having a fan rotor region;

a hub disposed concentrically relative to the fan casing;

a fan rotor that includes multiple swept fan blades, the swept fan blades being spaced apart around the hub and being capable of rotating at speeds providing supersonic working medium gas velocities over the blades to cause a shock in the gas adjacent the inner duct wall, each of the multiple swept fan blades having:

UTC '985 Patent Disclosure

A gas turbine engine fan stage 10 has blades 12 circumscribed by a case 42 that forms a fan duct (Figs. 1 and 2; col. 2, lines 42-44 and 56-58). The fan is rotatable about an axis 18 (Fig. 2, col. 2, lines 44-46).

The case 42 defines an inner wall in a region that is axially coextensive with the blade 12 (Figs. 1 and 2; col. 3, lines 58-67).

The hub 16, 20 and case 42 have the same centerline 18 and thus are concentric (Figs. 1 and 2; col. 2, lines 42-63).

The fan blades 12 are spaced apart around the hub. The blades are swept (col. 4, lines 11-17 and 24-29). The blades rotate at speeds high enough to experience supersonic velocities near their tips, and a shock 64 forms adjacent the inner duct wall (Fig. 2; col. 3, lines 30-40).

a tip profile that corresponds to the inner duct wall of the fan casing;

a leading edge that defines a variable sweep angle in a direction perpendicular to the axis of rotation, the leading edge including:

an inner region adjacent the hub, the inner region defining a forward sweep angle;

an intermediate region between the inner region and the fan casing, the intermediate region defining a rearward sweep angle; and

an outer region between the intermediate region and the fan casing, the outer region being translated forward relative to a leading edge with the same sweep angle as an outward boundary of the intermediate region to provide a sweep angle that causes the blade to intercept the shock.

The blade 12, seen in Fig. 2 projected into the radial plane of the drawing, has a tip profile that corresponds to the inner wall of the case 42 (Figs. 1 and 2; col. 3, lines 26-29).

The blade leading edge 28 has an intermediate region 70 with a sweep angle σ_1 and a tip region 74 with a sweep angle σ_2 , both of which vary with increasing blade height (Fig. 2; col. 4, lines 11-17 and lines 24-29).

A first height region between the blade root 24 (that is, adjacent the hub 16,20) and $r_{t-inner}$ is swept forward (Fig. 2; col. 5, lines 55-58).

The intermediate region 70 between $r_{t-inner}$ and $r_{t-outer}$ is swept rearward (Figs. 1 and 2; col. 4, lines 11-13).

The tip region 74 between $r_{t-outer}$ and the blade tip 26 is translated axially forward relative to a conventional blade to intercept the shock (col. 4, line 62, to col. 5, line 5).

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that the statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under § 1001 of Title XVIII of United States Code, and that such willful false statements made jeopardize the validity of this application or any patent issued thereon.

Date: 16th May 2003

F. Bruegelmans
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